Electromagnetism and the Brain
ECE 677
Spring 2022

Contact Information

Instructor: Assoc. Prof. John Seymour
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Office Hours: Thurs 2 – 4 pm or by appointment
Class: M/W 4-5:15 pm in Herzstein Hall HRZ 211

Course Objectives and Learning Outcomes

Course Objectives

Human brain activity is a specific form bioelectromagnetism, which is the multi-disciplinary study of the electromagnetic (EM) phenomena that arise in biological tissues. This class studies the considerable variety of "brain signals" and the generation of their corresponding EM fields that can be detected with electric and magnetic sensors. What is the intrinsic information of each signal type and in what context are those useful? How can EM stimulators be used to perturb brain activity? How do neuroscientists and clinicians differ in their use of neurophysiology tools, and how do we, as engineers, engage with both communities? We endeavor to answer these questions and more

We review the history and physics of neurophysiology and briefly cover the imaging correlate to EM techniques, namely the BOLD signal used in fMRI and intrinsic optical imaging. Topics include EM, biophysics, spectral analysis, forward modeling, reciprocity, source localization, and the electrode/insulator design.

This class will develop your intuition of brain signals by modeling the sources, then finding those sources after the signals are acquired. Your final team project will build a finite element model (FEM) of brain activity and analyze those signals in Matlab or Python. Teams will create current sources within a simple head model and virtually measure current and/or voltage based on their chosen technology. Homework will also include analytic and FEM problem solving. Basic signal processing is a pre-requisite but not the focus of this course.

Recommended prerequisite(s): Introductory courses in physics and time-series signal analysis, e.g.,ELEC 242. Mutually Exclusive: none.

Learning Outcomes:

1) Students will describe current challenges faced by neurophysiologists (neuroscientists and clinicians) and consider how engineering advances can contribute.

2) Students will understand the physiological basis of field potentials in its many forms, noninvasive or invasive: EEG, MEG, ECoG, sEEG, and LFP.

3) Students will be able to explain the key equations explaining current sources and volume conduction.

4) Students will understand the temporal and spatial scales of each of these signals relative

to their imaging correlates, e.g. fMRI and intrinsic optical imaging.

5) Students will use biophysical (forward) modeling tools and learn how these may be used to study neural activity, including field potentials.

6) Students will become familiar with source localization tools (inverse models) and how these may be used by neuroscientists and clinicians.

7) Students will cite major advances in neurophysiology and how these led to clinical and neuroscience breakthroughs.

Grade Policies

There will be homework problems, midterm exams, and a group project. Collaboration is optional on homework problems, but you must turn in your own work. Projects are collaborative. Homework problems can be turned in within 48hours past the deadline but at a 20% penalty. Exams are a solo activity and must be turned in at the time specified.

Grading:

Participation: 20%

Homework: 30%

Midterms: 30%

Group project and report: 20% (Team members will also grade one another)

Syllabus Change Policy

This syllabus is only a guide for the course and is subject to change with advanced notice.

Course Schedule (tentative and subject to change)

Module 1: EM & Field Potentials	Jan 10	1	History and physics of bioelectromagnetism		
	Jan 12	2	Synapses, cells, and brains	Malmivuo, Chapt. 5	
	Jan 17	3	Field potentials and the electro-quasistatic model	Naess et al., 2021; Perasan et al., 2018	
	Jan 19	4	Local field potentials and current source density	Buzsaki et al. 2012	HW 1 due
	Jan 24	5	EEG, MEG, ECoG, SEEG, LFP	Malmivuo, Chapt. 13	
	Jan 26	6	Imaging Correlates: Bold signal		
	Jan 31	7	Field potentials for clinical brain mapping	Guest lecturer: Prof. Nitin Tandon, MD, neurosurgeon	HW 2 due
	Feb 2	8	Physics of MEG: All models are wrong but some are useful	Malmivuo, Chapt. 14, Guest lecturer: Prof. John Mosher, PhD	
	Feb 7	9	Midterm #1		
	Feb 9	--	TBD		

Module 2: Forward and Inverse Modeling	Feb 14	10	H&H model using Matlab	Malmivuo, Chapt. 11	
	Feb 16	11	Current dipoles and ANSYS	Murakami, et al. 2015	
	Feb 21	12	Dipole density invariance, ANSYS continued.	Murakami, et al. 2015	
	Feb 23	13	Biophysics and NetPyNE	Dura-Bernal et al, 2019. Guest lecturer, Prof. Salvador Dura	HW 3 due
	Feb 28	14	Field potential modeling and NetPyNE	Dura-Bernal et al, 2019. Guest lecturer, Prof. Salvador Dura	
	Mar 2	15	Lead field theory	Malmivuo Chapt. 11.6	
	Mar 7	16	Brainstorm	Tadel et al., Guest lecturer: Prof. John Mosher, PhD	
	Mar 9	17	Applications of forward & inverse models		HW 4 due
	Mar 14	--	SPRING BREAK - NO CLASS		
	Mar 16	--	SPRING BREAK - NO CLASS		
Module 3: EM Stimulation	Mar 21	18	Introduction to stimulation modalities		
	Mar 23	19	Role of electrode design on tissue activation	Janson, et al. 2020	
	Mar 28	20	Brain mapping with stimulation		HW 5 due
	Mar 30	21	Transcranial magnetic stimulation	Malmivuo, Chapt. 22	
	Apr 4	22	Transcranial electrical stimulation (DC, AC, other)	Malmivuo, Chapt. 21	
	Apr 6	23	Course review		HW 6 due
	Apr 11	24	Midterm #2		
Module 4: Team Project	Apr 13	25	Project reports are due		
	Apr 18	26	Project presentations		
	Apr 20	27	Project presentations	(last day of class)	
	Apr 25	--	No exam		
	Apr 27	--	No exam		

Required Texts and Materials

Presented materials will be shared. You are required to download and reference the following resources, which are freely available. Some reading assignments will be made. Course book:

- **Malmivuo, Jaakko, and Robert Plonsey. 1996. "Bioelectromagnetism."** ***Medical and Biological Engineering and Computing*** **34: 9–12. Available at this link**

Important published articles we will reference:

- Buzsáki, György, Costas A. Anastassiou, and Christof Koch. 2012. "The Origin of Extracellular Fields and Currents-EEG, ECoG, LFP and Spikes." *Nature Reviews Neuroscience* 13 (6): 407–20. https://doi.org/10.1038/nrn3241.
- Dura-Bernal, Salvador, Benjamin A. Suter, Padraig Gleeson, Matteo Cantarelli, Adrian Quintana, Facundo Rodriguez, David J. Kedziora, et al. 2019. "NetpyNE, a Tool for Data-Driven Multiscale Modeling of Brain Circuits." *ELife* 8: 1–26. https://doi.org/10.7554/eLife.44494.
- Næss, Solveig, Geir Halnes, Espen Hagen, Donald J Hagler, Anders M Dale, Gaute T Einevoll, and Torbjørn V Ness. 2021. "Biophysically Detailed Forward Modeling of the Neural Origin of EEG and MEG Signals." *NeuroImage* 225 (September 2020): 117467. https://doi.org/10.1016/j.neuroimage.2020.117467.
- Pesaran, Bijan, Martin Vinck, Gaute T. Einevoll, Anton Sirota, Pascal Fries, Markus Siegel, Wilson Truccolo, Charles E. Schroeder, and Ramesh Srinivasan. 2018. "Investigating Large-Scale Brain Dynamics Using Field Potential Recordings: Analysis

and Interpretation." *Nature Neuroscience* 21 (7): 903–19. https://doi.org/10.1038/s41593-018-0171-8.
- Tadel, François, Sylvain Baillet, John C Mosher, Dimitrios Pantazis, and Richard M Leahy. 2011. "Brainstorm: A User-Friendly Application for MEG/EEG Analysis." *Computational Intelligence and Neuroscience* 2011. https://doi.org/10.1155/2011/879716
- Murakami, Shingo, and Yoshio Okada. 2015. "NeuroImage Invariance in Current Dipole Moment Density across Brain Structures and Species : Physiological Constraint for Neuroimaging." NeuroImage 111: 49–58. https://doi.org/10.1016/j.neuroimage.2015.02.003.
- Janson, Andrew P., Daria Nesterovich Anderson, and Christopher R. Butson. 2020. "Activation Robustness with Directional Leads and Multi-Lead Configurations in Deep Brain Stimulation." Journal of Neural Engineering 17 (2). https://doi.org/10.1088/1741-2552/ab7b1d

Classroom Policy

Lectures will be given in person. Students are expected to be actively engaged in the classroom. Every student in the classroom is expected to properly wear a mask or face cover per the Rice Crisis Management Policies.

Rice Honor Code

In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Resource Center

If you have a documented disability or other condition that may affect academic performance you should: 1) make sure this documentation is on file with the Disability Resource Center (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with me to discuss your accommodation needs within the first two weeks of the class. All discussions will remain confidential.